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A hybrid approach for character modeling using geometric primitives and shape-from-shading algorithm

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Abstract

Organic modeling of 3D characters is a challenging task when it comes to correctly modeling the anatomy of the human body. Most sketch based modeling tools available today for modeling organic models (humans, animals, creatures etc) are focused towards modeling base mesh models only and provide little or no support to add details to the base mesh. We propose a hybrid approach which combines geometrical primitives such as generalized cylinders and cube with Shape-from-Shading (SFS) algorithms to create plausible human character models from sketches. The results show that an artist can quickly create detailed character models from sketches by using this hybrid approach.

Keywords: Sketch based modeling; Character; Modeling; Shape-from-shading; Sketch

1. Introduction

Organic modeling of 3D characters is a challenging task when it comes to correctly modeling the anatomy of the human body. An artist views the human body in the form of several parts which can be modeled using simple primitive objects. For example, limbs (arms and legs) can be approximated with cylinders, head can be approximated with spheres or ellipsoids. However some artists make character sketches in which the characters are wearing armor, and clothes. We propose a 'cube' as a new primitive which can be used to model armor and clothes.

Most sketch based modeling approaches generate base mesh models only without details. Realistic models require details on their surface. To create more realistic looking models, artists tend to use sculpting packages such as ZBrush [1], or Mudbox [2]. These packages provide tools which are often difficult to learn and master by novice artists, and are not designed to be used in a more natural way. Thus the artist is required to give a keen attention to detail, often making the entire process very laborious and time consuming. These packages also require computers with high specifications for GPU with considerable amount of memory, as most of the features are designed to be executed on the GPU, thus making them less favorable for 3D artists focusing on low resolution 3D graphics for indie games.

Shape-from-Shading provides a promising and efficient method to create details from images. The idea for reconstructing 3D surface details from images and combining it to a low-polygon base mesh comes from the philosophical work by Koenderink [3]. In this paper the author discusses in detail the philosophy behind generating 3D surfaces from shaded/lighted images. Several SFS techniques have taken inspiration from Koenderink work such as [4], [5], and [6].

Our proposed hybrid approach solves the problem of producing better quality character models than the previous sketch based modeling (SBM) approaches [7], through easy inputs by integrating SBM approaches given in [7] with the shape-from-shading algorithm in [9]. The work presented in [7] and [9] has inspired us to combine them together to produce a hybrid technique leading to better results.

Our main contributions are as follows:

1. We have proposed a novel and hybrid approach which harnesses some of the techniques of [7] and [9] to generate

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good quality character models through sketching. The previous techniques in Sketch Based Modeling [7] generate simple base mesh models, thus limiting the artist to create highly detailed models.
2. Our approach provides artists two additional tools in addition to the generalized cylinder including cube and ellipsoid as geometric primitives to create base mesh models quickly and easily.
3. Instead of requiring the artist to provide a template source mesh as input as in [10], our approach instantly generates relief mesh using shape-from-shading algorithms, which can be easily transferred to the target base mesh.
4. Utilizing the technique in [9], we generate surface details from a single picture or sketch, and provide tools to interactively add the details to the base mesh.

2. Related work

Sketch based modeling systems can be roughly categorized in solid modeling, and organic modeling systems. Notable examples of sketch based solid modeling systems are Google SketchUp [11,12], and more recently [13]. On the other hand organic sketch based modeling systems provide tools to create character models mainly using feature curves, and suggestive contours [14] etc. Organic modeling systems provide tools to the artists to create 3D models from simple primitives such as ellipsoids and using inflation techniques to inflate a closed 2D region/sketch (e.g. a circle, oval etc.) such as Teddy [15], and FiberMesh [8]. In [7], Gingold et al. used generalized cylinder and ellipsoids for modeling of organic models directly from a single view model, and provided annotations to artists so they can manipulate the models easily and quickly. However their system provides a limited set of tools to the artist for modeling and only provide two primitives (cylinder and ellipsoid). Most artists make use of more primitives to model a human character. One important primitive used by artists is the box primitive as demonstrated in tutorial video by the leading comic artist Stan Lee [16]. In this tutorial, he tells us how easily we can decompose a human body into simple primitive geometric shapes.

In FiberMesh [8], the authors have proposed a system to add details to simple 3D models. However using this system, adding finer details is not easy and requires great attention to detail for the novice artist. Moreover very subtle details are not very easy to add. In [17], the authors have presented an intuitive technique for mesh editing via sketching instead of vertex manipulation.

Shape-from-Shading (SFS) has undergone considerable amount of research in the past decades. Several excellent surveys exist on SFS such as [18,19]. SFS algorithms have immense applications not only in the animation/gaming industry but also in the archeological research where scientists are reconstructing ancient artifacts and base reliefs to preserve them in digital form such as Project Mosul (http://projectmosul.org/). Hahn et al. has proposed a two-step method for surface reconstruction using 2D strokes and a vector field on the strokes. They have used TV and H1 regularization with a curl-free constraint for obtaining a dense vector field and using this dense vector field to obtain the final height map. However this method is very computation intensive and requires complex GPU implementation to speed up the computation. This method also involves solving energy minimization functionals. Lee and Kuo [32] used the brightness constraint and the smoothness constraint. Surfaces were approximated by the union of triangular surface patches. The vertices of the triangles were called nodal points and only nodal depths were recovered. They have used interpolation to recover depth at the pixels. For each triangular patch, the intensity of the triangle was taken as the average intensity of all pixels in the triangle and the surface gradient of the triangle was approximated by the cross product of any two adjacent edges of the triangle. This established a relationship between the triangle intensity and the depth at its three nodal points. Tsai and Shah [20] presented a very fast and simple algorithm for computing the height map from a single greyscale image. Their approach uses a linear approximation of reflectance in the z axis, and the results are very convincing. In [21] the authors have presented a new algorithm for base relief reconstruction using Adaptive Histogram Equalization, which optionally uses a template model to compute the height fields via orthogonal or perspective projection. The shape features of the base relief are enhanced by using gradient scaling factors. The results of this approach are in general better looking than other techniques; however, as pointed out by the authors, the basic drawback of this technique is without optimization it is time consuming taking around an hour to process a high resolution photograph.

Several researchers have addressed the problem of stitching/transferring details from one mesh to another mesh. To stitch the details onto the base mesh, our hybrid approach utilizes the Discrete Exponential Map (DEM) algorithm first proposed by Schmidt et al. [22] and then generalized by Takayama et al. [10]. In [23] the authors have proposed a novel approach for mesh cloning approach based on pyramid spherical coordinates driven by boundary loop, which extends an existing algorithm for computing offset membrane on mesh. The source and target meshes are mapped onto a 2D parametric domain using geodesic polar maps. During cloning, the boundary loop of the region of interest (ROI) on the target mesh is fitted in real time by B-spline curve to register the boundary loop of the source ROI. Via the reconstructed boundary loop, the ROI is deformed to register the target mesh by pyramid spherical coordinates to ensure that the clone result is seamless and natural.

For modeling a base mesh model, our system mainly draws inspiration from Gingold et al [7] and in addition to this, our system aims at enhancing the system by providing a new shape primitive for modeling i.e cube. It uses the same definition for creating the generalized cylinder as well as the ellipsoid. Moreover we use the technique in [9] to generate a 3D surface from purely 2D images by computing the height values at each pixel. The authors in [9] have proposed a novel SFS method based on hybrid reflection model which contains both diffuse reflectance and specular reflectance. According to the authors, when discrete characteristic of digital images is considered, finite difference approximates differential operator. The reflectance map equation described by a partial differential equation (PDE) turns into an algebraic equation about the unknown surface height. We then interactively add details to the bash mesh created using geometric primitives to generate plausible character models. Thus our system poses some improvements by providing base mesh modeling, detail generation, and detail integration in the single interface.

3. System overview

By combining the techniques presented in [7] and [9], we have developed a modeling system which is composed of two main modules: (1) base mesh modeler, and (2) surface detail modeler. In this section, we explain all the modeling primitives and the controls our system provides to manipulate/modify the primitive models to depict different parts of a knight model.

3.1. Base mesh modeler

In this module, we provide three primitive shapes to allow artists to quickly model a base mesh from a single view. Our system provides tools which are simple to use and quickly models the primitives using sketching input/gestures. The primitive shapes provided are (1) generalized cylinder, (2) cube, and (3) ellipsoid. The artist can choose from these primitives to model different parts of the character. To create a primitive inside the window, the artist first selects the primitive from the toolbox, and draws a stroke in the main window. The system automatically creates a primitive with default size. The system also automatically connects two primitives together. To manipulate the shape of a primitive, our system provides several controls to the artists as discussed in

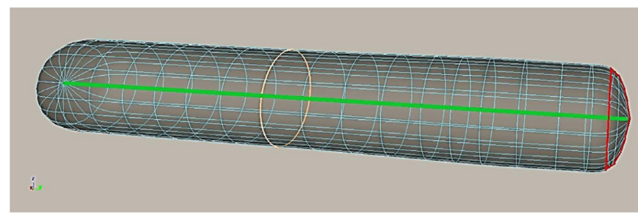

Fig. 2. A generalized cylinder.

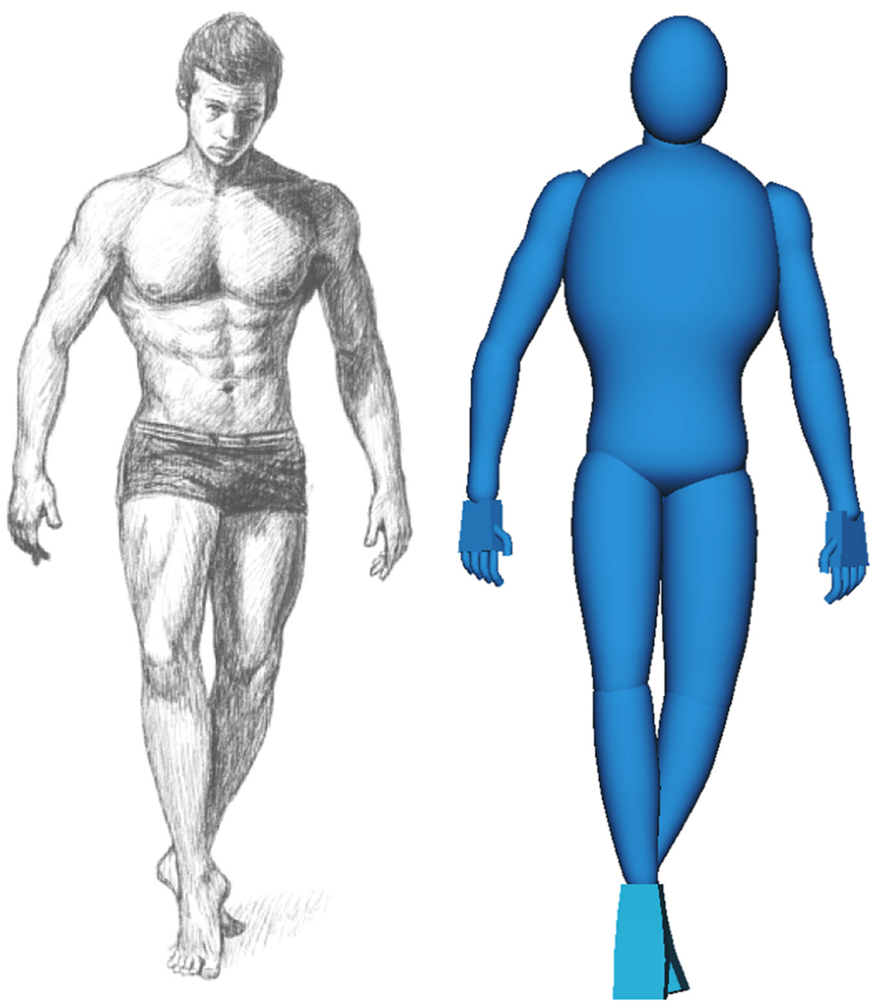

Fig. 1. Bodybuilder character created using our system's base mesh modeler from a single sketch. (*Sketch retrieved from: http://luneder.deviantart.com/art/Male-figure-sketches-1-410274631.*)

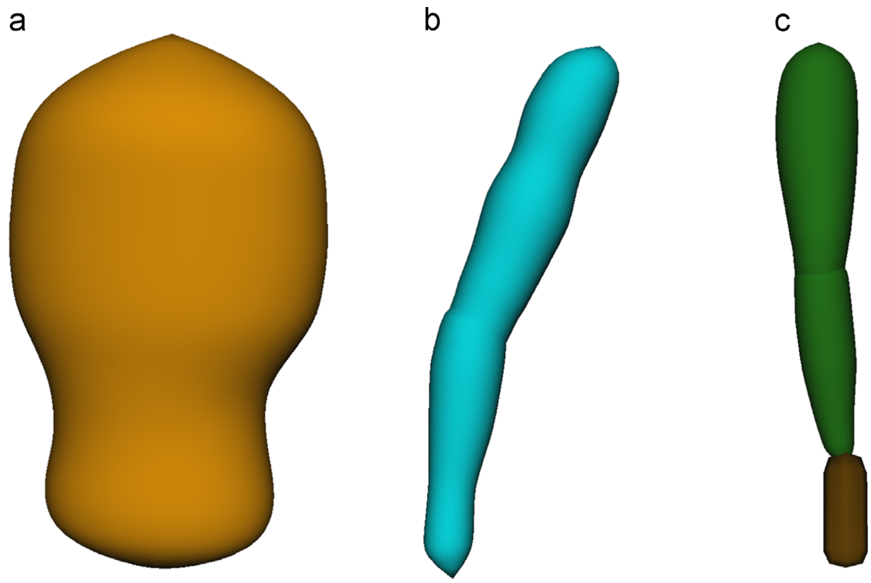

Fig. 3. Body parts modeled using generalized cylinders. (a) torso, (b) arm, and (c) leg.

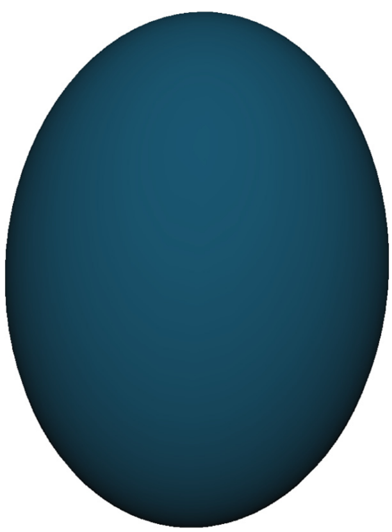

Fig. 4. The head of the bodybuilder character was modeled using an ellipsoid.

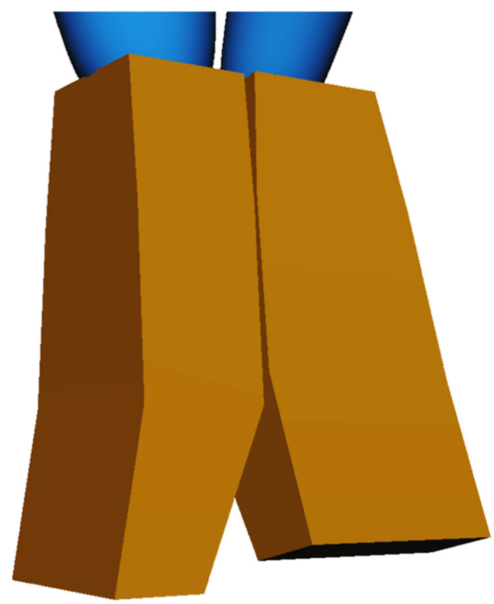

Fig. 5. Shoe of bodybuilder character modeled using a cube.

Section 3.1.4. Fig. 1 demonstrates a bodybuilder character modeled using the base mesh modeler of our proposed system.

3.1.1. *Generalized cylinder*

We use a parametric definition of the generalized cylinder given in [7]. A generalized cylinder is also known in research literature as a 'sweep surface' [24,25]. It is generated when a cross section shape is swept across a spine curve. A spine curve is a B-spline curve defined by a set of control points. The equation of the surface of the generalized cylinder is defined as follows:

$$P(t,r) = p(t) + v^t(r)n(t) + u^t(r)b(t) \tag{1}$$

where $p(t)$ is the control point on the curve at parameter t. $n(t)$ is a unit normal to the curve at the point $p(t)$. $b(t)$ is a vector perpendicular to tangent vector and the unit normal vector at the point $p(t)$, acquired by the cross product. $v^t(r)$ and $u^t(r)$ are the components of the point on the cross section at the control point $p(t)$.

We have used an ellipse as a cross section curve. A cross section is thus a 2D B-spline curve drawn on a 2D plane perpendicular to every B-spline curve point $p(t)$. We define the cross section curve at the point $p(t)$ as follows:

$$u^t(r) = \cos\theta(t)s^u(t)u(r) - \sin\theta(t)s^v(t)v(r) \tag{2}$$

$$v^t(r) = \sin\theta(t)s^u(t)u(r) + \cos\theta(t)s^v(t)v(r) \tag{3}$$

where $s^u(t)$ and $s^\nu(t)$ are the scaling factors in the u and ν coordinates of the cross section curve. θ is the angle of rotation of the cross section.

The end caps of the cylinder are created in tangent continuous fashion, and the cross section scale keeps decreasing as it approaches the end point of the cylinder. The smoothness of the cylinder can be controlled by the user by specifying the number of subdivision steps as explained in Section 4.

Fig. 2 shows a generalized cylinder. In the figure, the cross section is highlighted in orange color, the end caps are shown with red outlines, while green curve shows the spine curve.

In Fig. 3 the torso, legs and arms of the male bodybuilder character were modeled using a generalized cylinder.

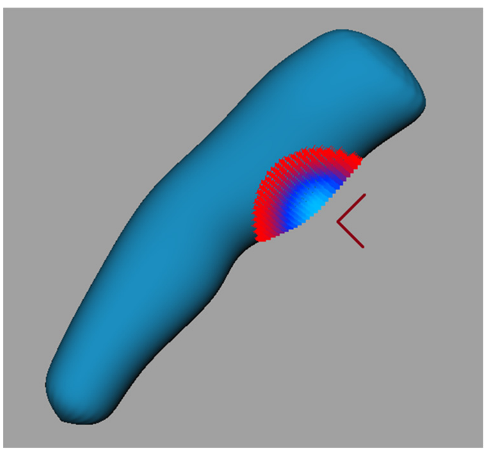

Fig. 6. Mesh manipulation. The axes allow the users to pull or push the mesh in the desired direction.

3.1.2. Ellipsoid

We have used a general ellipsoid, also known as the triaxial ellipsoid. Mathematically, it is defined as a quadratic surface given in Cartesian coordinates by

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1 \tag{4}$$

where the semi-axes are of lengths a, b, and c. An ellipsoid can be used to model the head and breasts of a character. An ellipsoid can be selected from the tools bar and dragged onto the canvas area. Here the artist can scale, rotate or translate the ellipsoid to better align with the sketch. An Ellipsoid is geometrically akin to the generalized cylinder except that its spine curve length is equal to the cross section radius of the central cross section (Fig. 4).

3.1.3. Cube

A cube is a simple geometrical structure which can be used to model armor and suits of characters. It can also be used to quickly model shoes of the character. A cube width can be scaled, and then it can be rotated to form different parts of the suit/armor of character models such as knee pads, belts, shoulder guards etc.

Fig. 5 shows shoe of the bodybuilder modeled using a cube.

3.1.4. Mesh manipulation/modification controls

Our system provides simple controls to the artists to manipulate and modify the mesh geometry. Mesh

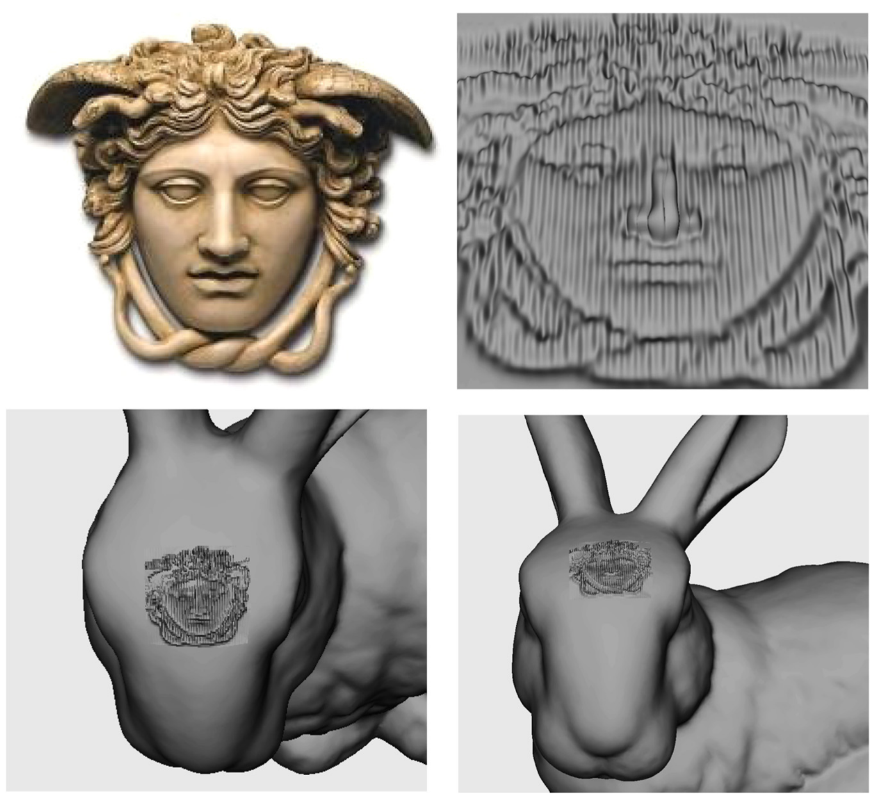

Fig. 7. Medusa relief (top left). A detailed surface of medusa relief (top right). Show detailed surface added to the head of the bunny (bottom images). (*Image retrieved from Medusa image: http://www.belladonna.de/haupt-medusa-p-2678.html.*)

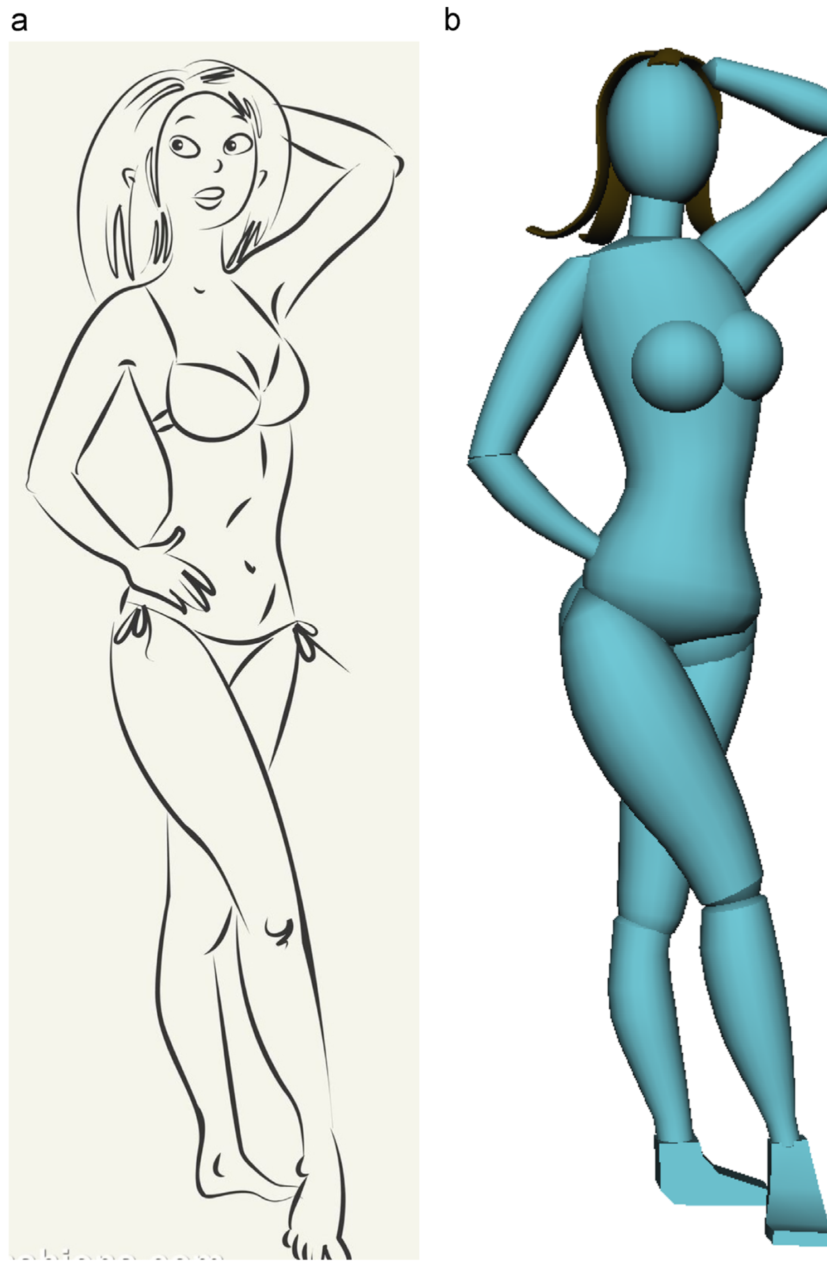

Fig. 8. (a) Female character sketch and (b) its completed model created using geometric primitives. (*Sketch retrieved from www.sketchesfashions.com.*)

manipulation controls in our system have been inspired by Gingold et al [7], who provided annotations and controls to the user to manipulate the primitives, such as connection curve annotation for connecting two or more primitives, mirror annotation to create a copy of the primitive and reflects it across the symmetry plane of another primitive. We have used a subset of these controls in order to match our mesh manipulation requirements.

As shown in Fig. 6, a user can select one or more points on the surface of a primitive and move them to modify the shape of the primitive. The system allows the user to rotate, translate and scale a set of vertices. When a user selects a vertex on the base mesh, the selected point along with its neighboring vertices is selected to allow the user to modify the mesh in a smooth manner.

3.2. Surface detail modeler

This is the second module of our system, which allows an artist to generate finer details onto the base mesh using shape-from-shading algorithm and detail transfer techniques. This module is responsible for producing the final detailed character model.

3.2.1. Relief mesh generation via shape-from-shading algorithm

Once the base mesh is created, our system allows the artist to integrate details to the base mesh to give it a more detailed and finished look. To attach surface details to the base mesh, we first generate a relief mesh from a photograph/sketch. In this step the artist can either provide the photograph/snapshot directly from the

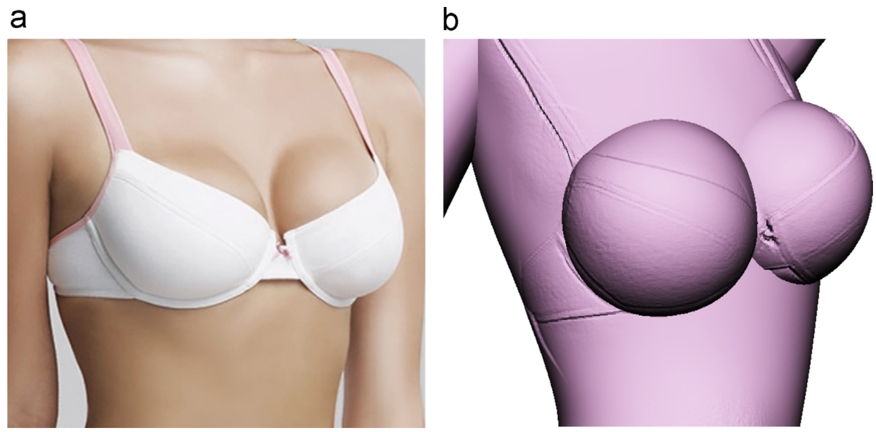

Fig. 9. (a) Details of the bra generated using an image and (b) transferred onto the breasts of the female character above.

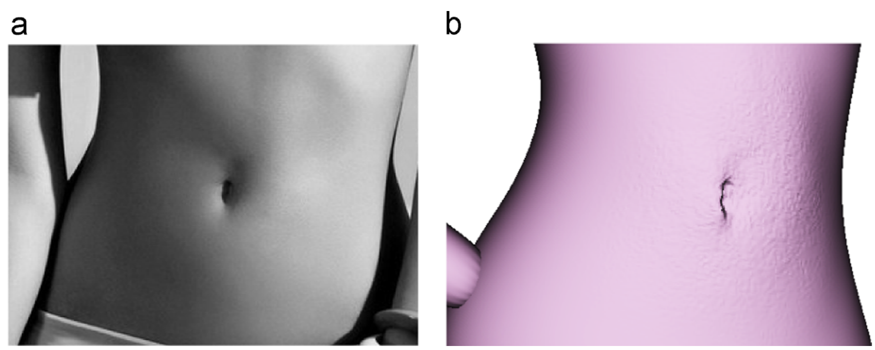

Fig. 10. (a) Details of the abdomen generated using an image and (b) transferred onto the lower torso base mesh of the female character in Fig. 8.

input sketch, or retrieve an image from the web which looks similar to the portion of the input sketch the artist needs to use for shape-from-shading. Our system utilizes the shape-from-shading algorithm proposed in [9] to reconstruct the surface details separately. The reason we chose to implement the algorithm in [9] is because it avoids the complex and computationally heavy energy minimization computations and is relatively simple to implement. The SFS algorithm is not meant to separate details from the sketched character but to generate 3D relief details directly from a photograph. Thus this is very easy to perform as it only requires the artist to select a photo from the web that can closely match the details of a particular part of the input sketched character such as armor details, suit details etc., which our system accepts to generate details. For integrating the details onto the base mesh surface, our system employs Discrete Exponential Map algorithm [10]. This is a semi-automatic method to incorporate the details onto the base mesh, which requires the artist to manually select a region of interest.

The input to this module is a single image or sketch which can be colored or in gray scale. The idea is to calculate the height values at each pixel using the hybrid reflectance map equation, and iteratively refine the height values.

The hybrid reflectance equation presented in [9] has the form of

$$R(p,q) = (1-\omega)R_d(p \cdot q) + \omega R_s(p,q) \tag{5}$$

where $p(x,y) = -\frac{\partial z(x,y)}{\partial x}$ and $q(x,y) = -\frac{\partial z(x,y)}{\partial y}$ denote the x and y-partial derivatives of reconstructed 3D surface height $z=z(x, y)$ with respect to the image coordinates x and y respectively. $\omega \in [0,\ 1]$ is the factor of specular component. From this equation, the reflectance map equation is derived, which is given by Yang and Han [9]

$$(1-\omega)\frac{pp_0+qq_0+1}{\sqrt{p^2+q^2+1}\sqrt{p_0^2+q_0^2+1}} + \omega\left(\frac{pp_h+qq_h+1}{\sqrt{p^2+q^2+1}\sqrt{p_h^2+q_h^2+1}}\right)^K = \frac{I(x,y)-I_{\min}}{I_{\max}-I_{\min}} \tag{6}$$

where $I_{\max}$ and $I_{\min}$ are the acquired maximum and minimum intensities of image $I(x, y)$ respectively. This SFS algorithm is fast to compute. The authors have used a hybrid reflectance model which is more prone to real reflectance than Lambertian shading model or Torrance–Sparrow shading model [26], which was used in previous SFS algorithms. The intensity gradient is in the direction that the shape of surface changes most, so directional derivative of image is used as parts of objective function in the algorithm. The reflectance map equation described by PDE turns into an algebraic equation about the unknown surface height, which is easy to compute.

Our aim is to compute the z values at each pixel. The iterative formula used by Yang and Han [9] is given as

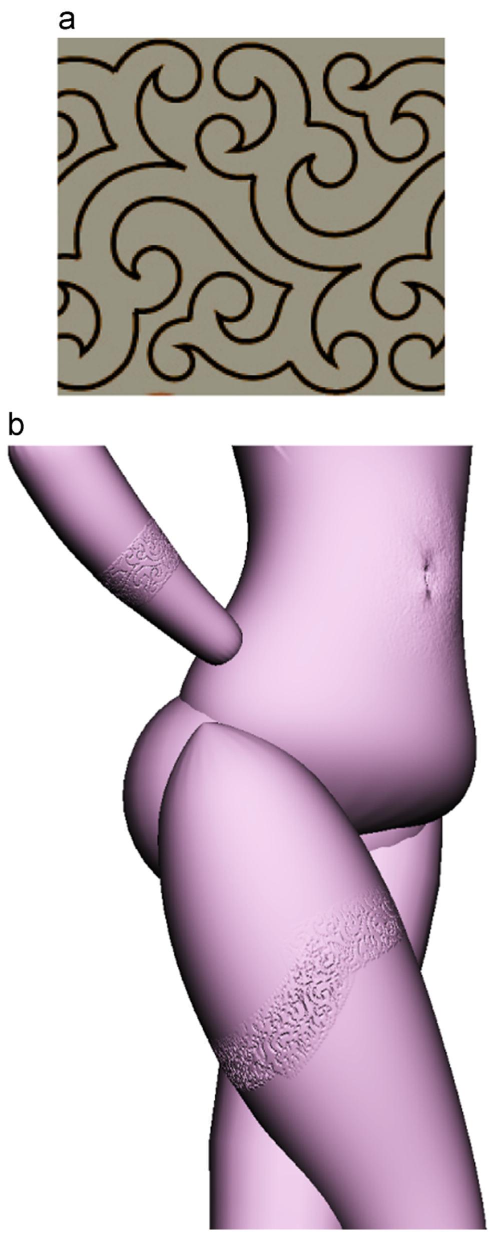

Fig. 11. (a) Details of the right arm and leg of the female generated using an image pattern and (b) details transferred onto the right arm and leg base mesh of the female character.

follows:

$$z_{i,j}^{(k+1)} = z_{i,j}^{(k)} + \mu \times F\Big(z_{i-2,j}^{(k)}, z_{i-1,j}^{(k)}, z_{i+1,j}^{(k)}, z_{i+2,j}^{(k)}, z_{i,j-2}^{(k)}, z_{i,j-1}^{(k)}, z_{i,j}^{(k)}, z_{i,j+1}^{(k)}, z_{i,j+2}^{(k)}, z_{i-1,j-1}^{(k)}, z_{i-1,j+1}^{(k)}, z_{i+1,j-1}^{(k)}, z_{i+1,j+1}^{(k)}\Big) \tag{7}$$

Here, $k = 1,2,\ldots$ is taken as the iterative time, μ is the iterative rate. The authors have suggested to stop the computation when iterative time limitation is arrived or error criteria are satisfied. However our experiments have shown that the height map achieved after the 5th iteration is acceptable enough. The detailed formulas for the second term in the above equations are given in the paper [9].

Fig. 12. Detailed model using SFS algorithm.

Fig. 7 demonstrates a 3D surface generated from a Medusa relief and then the details transferred to the bunny model.

3.2.2. Detail transfer from relief mesh to target base mesh

We have utilized GeoBrush algorithm presented in [10] to transfer the details from source mesh to the target base mesh in a semi-automatic manner. In this semi-automatic and interactive step, the system first increases the number of polygons of the target base mesh to approximately match with that of the source

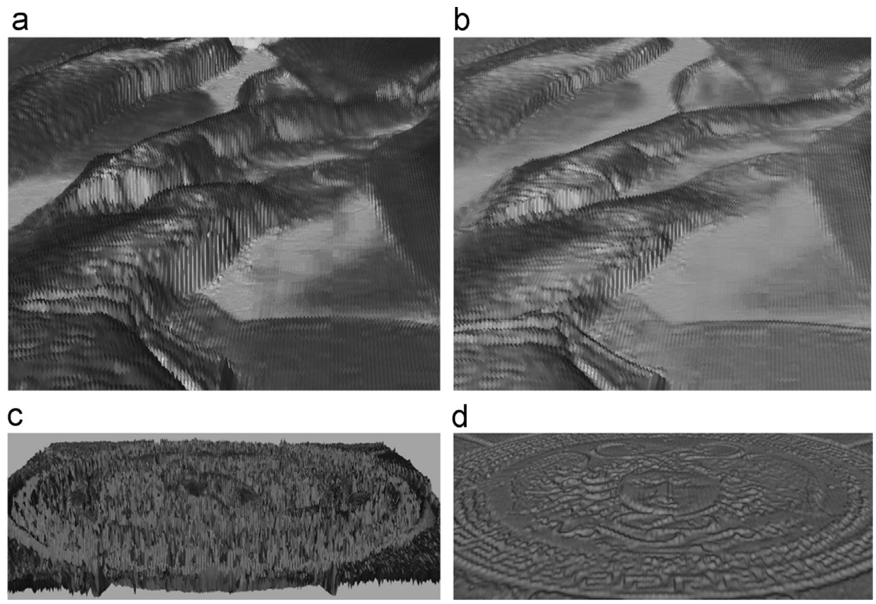

Fig. 13. (a,c) $\mu=0.5$ (b,d) $\mu=0.02$.

Fig. 14. smoothness variations in generalized cylinder with Subdivision=2, and Subdivision=5.

relief mesh, by subdividing the target mesh. We then require the artist to select a region on both the reconstructed mesh and the target mesh (obtained from shape-from-shading) using painting. We establish a rough correspondence between the source and target meshes as the topology of both the surfaces can vary. We then compute the parameterization and mapping from the source mesh to the target mesh using the Generalized Discrete Exponential Map algorithm as introduced in [10], which is a generalized version of the DEM algorithm presented by Schmidt et al. [22]. For any surface, DEM is a parameterization of the surface centered at a point p on it. We find the geodesic distance curves originating from p following the same origin as the tangent plane at p, using Djikstra's shortest path algorithm.

Fig. 8 shows a female character modeled using the base mesh modeler and then detailed using the SFS algorithm. In Fig. 8(b), the entire base mesh of the female character was modeled using geometric primitives. The torso, arms, hair and legs were modeled using generalized cylinder. The head and breasts were modeled using a spheroid. The feet were modeled using a cube.

After the artist has completed the base mesh of the model, he/she can proceed with adding the details to this model. Fig. 9 shows the details of the bra generated using an image and transferred onto the breasts base mesh of the female character in Fig. 8.

Fig. 10 shows the details of the abdomen generated using an image and transferred onto the lower torso base mesh of the female character in Fig. 8.

Fig. 11 shows the details of on the right arm and leg of the female generated using an image and transferred onto the right arm base mesh of the female character in Fig. 8.

Fig. 12 shows the final female character with necessary details added to the base mesh.

4. Implementation

We have implemented our system in C++ on an HP Z400 workstation with Intel Xeon CPU 3.33 GHz, Nvidia GeForce GTX 560Ti, 8GB RAM and running Windows 7 64-bit. For SFS algorithm, we used $k=10$, as the maximum iterative time criteria, and μ was set as 0.02, as the higher values tend to distort the overall depth of the image, as shown in Fig. 13.

The spine curve of the generalized cylinder is composed of multiple control points, which approximates the curve with a B-spline curve. We have initialized the spline curve to contain a minimum of 3 control points. The user has the option to specify the number of subdivisions of the spine curve to set the desired smoothness. We have used a subdivision algorithm from Tony et al. [27] for smoothing the spine according to the number of subdivision steps specified by the user. In this way a relatively rough curve can be approximated with a smooth B-spline curve. This is demonstrated in Fig. 14. The cylinder drawn on the left has been subdivided to 2 levels, while the cylinder on the right has been subdivided to 5 levels.

For transferring details from the source mesh onto the target base mesh, we have utilized the GeoBrush demo program provided by the authors at (http://igl.ethz.ch/projects/geobrush/). Here the artist can very easily perform the operation of selecting the source mesh and the target mesh and the system performs the appropriate details transfer.

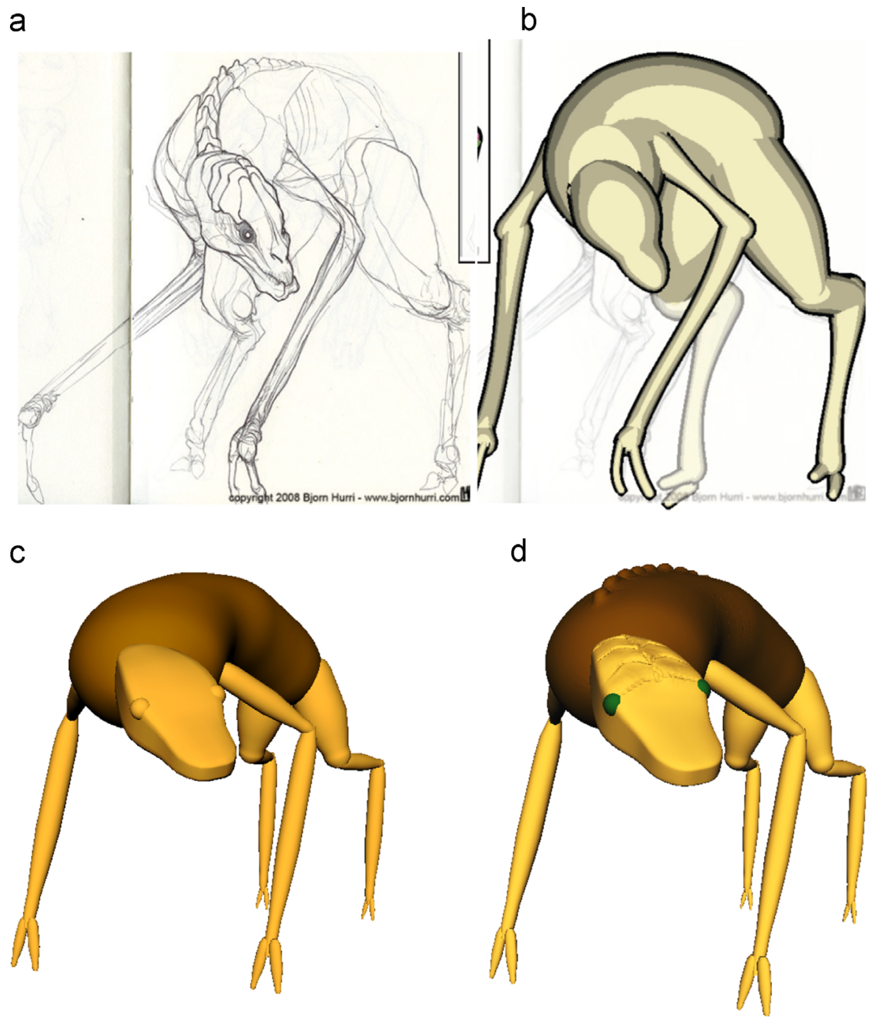

Fig. 15. (a) Input sketch of the monster model (b) monster model created using Gingold et al. [7], (c) base mesh of monster model created using our approach, and (d) details added to the base mesh.

5. Results and discussion

We tested our system with students in our lab. The students found it easy and intuitive to quickly model the base mesh from a single picture. The users also found it very intuitive to generate a 3D surface from a photo and add it to the base mesh in order to show details on a mesh.

Our system can be used for rapid prototyping of character models and can find applications in game development studios, animation studios, online gaming etc. We have focused our system towards novice animators and artists.

Our approach has been designed to create prototypical base mesh models in less time as compared to the ones created via Maya. However due to rapid prototyping as the main design focus, our technique cannot model highly accurate characters. With normal Maya modeling, it is very time consuming to modify the primitive shapes to resemble the different parts of the input sketch. On the other hand with our approach, an artist can quickly modify the primitive shapes using sketching gestures, and vertex manipulation tool.

Creating different parts of the human body from primitives is much easier and faster than modeling with Maya etc.

Fig. 15 shows a comparison of a monster model created using the approach of Gingold et al. [7] and our approach. As compared to the models created by Gingold et al. [7] in Fig. 15(b), Fig. 15(c, d) shows that our approach can create more detailed prototypical models. Our approach took nearly 15 min to create the model.

6. Conclusion

We have presented a hybrid sketch based modeling system combining the features from existing systems such as [7] and shape-from-shading [9] to allow artists to quickly model the base mesh of the character as well as add details to the base mesh. Our system provides intuitive tools to add details to the base mesh. In contrast to the popular commercial animation packages such as Maya [29], and 3Ds Max [30], which have a steep learning curve, our system allows the artists to quickly create a base mesh from a single view via simple strokes, and utilizing the power of primitives (generalized cylinders, cubes, and ellipsoids). Moreover, our system allows the artists to quickly add details to the surface of the base mesh by generating a 3D surface from a photo with minimum effort.

We believe that our system makes a fresh attempt at pushing the sketch based modeling systems beyond their boundaries.

7. Limitations and future work

There are several limitations of our system including:

1. The mesh manipulation controls are not easier to learn and can be improved in future by simplifying the controls.
2. In contrast with [7], our system does not make use of Laplacian mesh editing [28] to modify meshes in a more artists friendly manner. This is an important feature that is now being embedded in popular modeling packages such as Blender [31], and we plan to add this feature to our system in future.

Our system can be further improved through the following work:

1. We would like to add more features to control and manipulate the primitives smoothly, and add details to the base mesh.
2. We would like to add the features to deform the feature curves of the modeled character to better match those of the input sketch.
3. We would like to add features to allow the artist to fully automatically stitch/transfer the details from SFS algorithm onto the base mesh without any manual interaction.

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